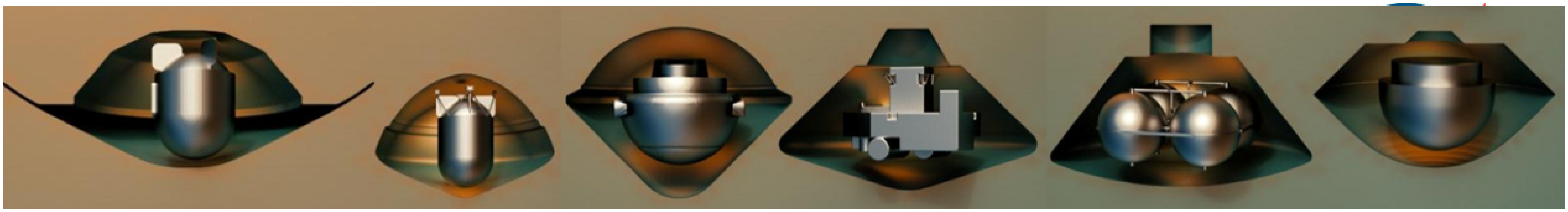
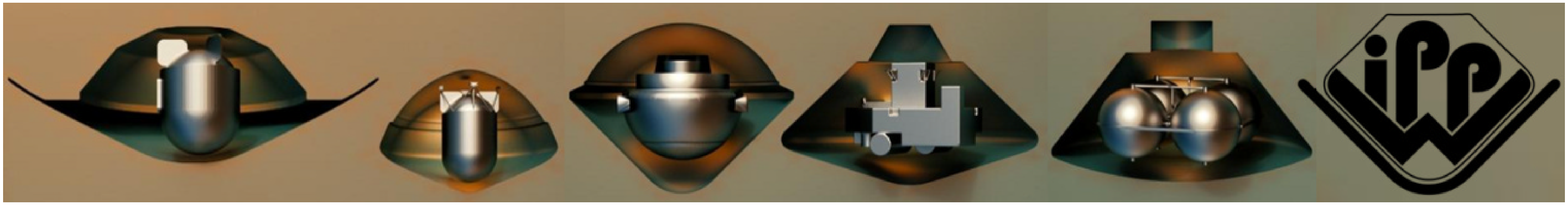


Entry, Descent, and Landing Systems Short Course

Subject: Modular Honeycomb-Packed Polymer Based Ablative Heatshields

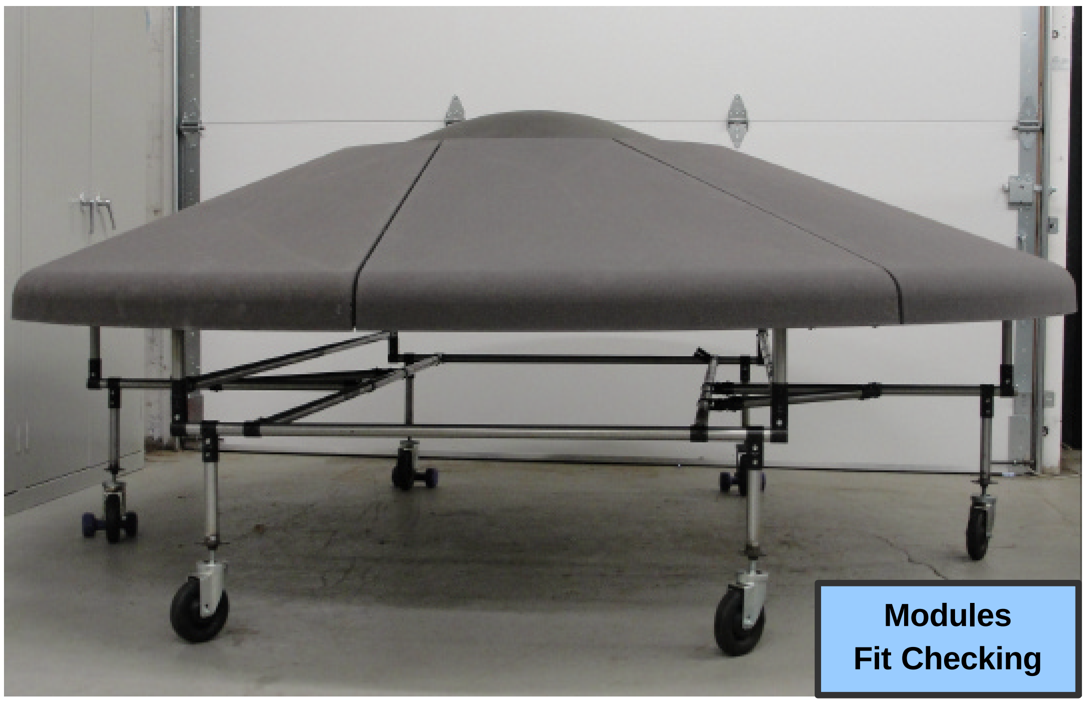
Author: William M. Congdon, Director
ARA Ablatives Laboratory

sponsored by
International Planetary Probe Workshop 10
June 15-16, 2013
San Jose, California



EDL TECHNOLOGY SHORT COURSE
INTERNATIONAL PLANETARY PROBE WORKSHOP-10
SAN JOSE, CALIFORNIA – 15-21 JUNE 2013

MODULAR HONEYCOMB-PACKED POLYMER-BASED ABLATIVE HEATSHIELDS
(2.65-m MANUFACTURING DEMONSTRATION UNIT)



Modules
Fit Checking

Principal Investigator:
William M. Congdon
ARA Ablatives Laboratory (ABL)
Applied Research Associates
Centennial, Colorado 80112
303 / 699-7737

NASA ISPT Contract NNM07AA93C

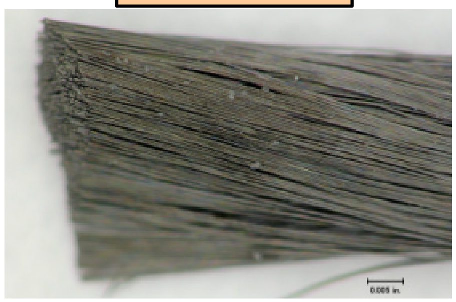
EXAMPLES OF CONSTITUENTS FOR CHARRING ABLATOR MATERIALS

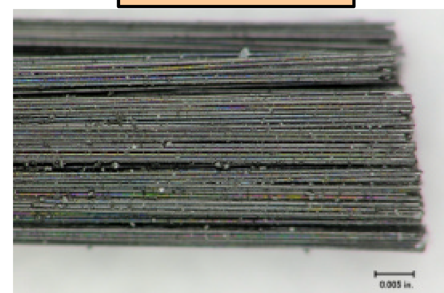
Polymer Resin

Carbon Fiber

Silica Fiber

SiC Fiber



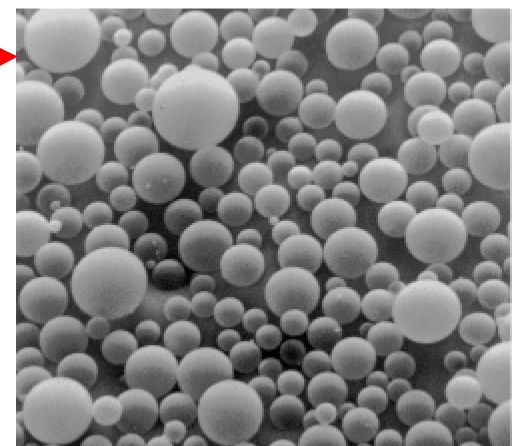


Phenolic MB

Also Ground Cork

Carbon MB

Silica MB



70-100 µm

ABLATOR REINFORCING HONEYCOMB – LAB PRODUCTION AT ABL

Standard H/C for ARA Ablators is 1.0-In. Cell Size, Large-Cell, Quartz Honeycomb
(Also: Different Cell Size, Different Fabric Thickness, Different Fabric Materials)

TYPICAL PRODUCTION COMPOUNDING OF POLYMER-BASED ABLATOR

Ablator Compounds Contain Resin, Chopped Fibers, Microballoons, Other Fillers, and Special Additives

No. 2 – Mixed Polymer Resin

No. 3 – Mixed-In Carbon Fibers

No. 4 – Blended-In Ground Cork

No. 5 – Mixed-In Microballoons (Ph)

No. 8 – Fully Mixed Ablator Compound

Compound Transfer to Drying Trays

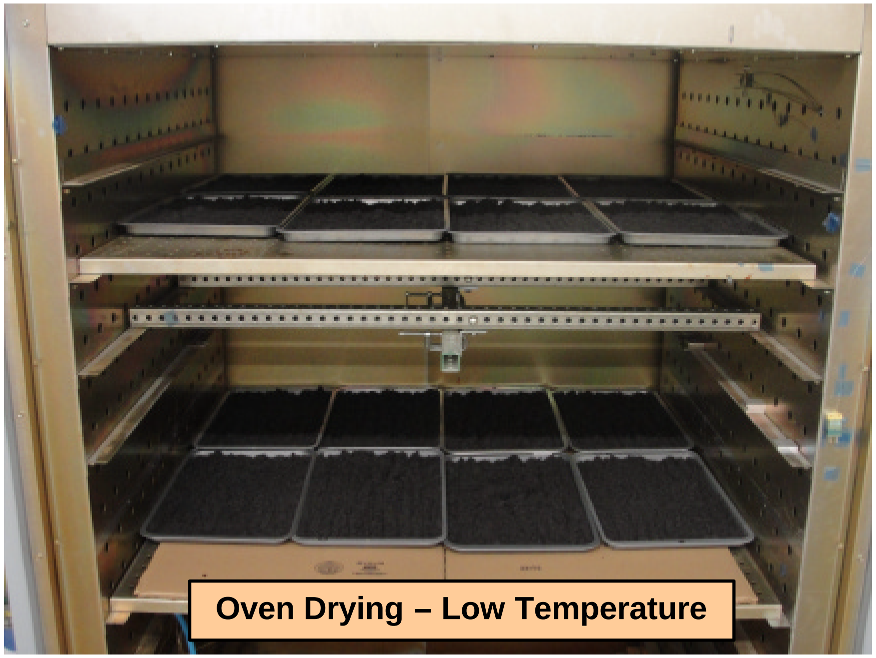
MIXED COMPOUND NEEDS TO BE CHOPPED, SPREAD THIN, AND DRIED

Ablator Compounds Contain Solvents that Require Removal Via Chopping Plus Air or Oven Drying

Compound from Mixer

Before Chopping and Spreading

Chopped – Air Drying

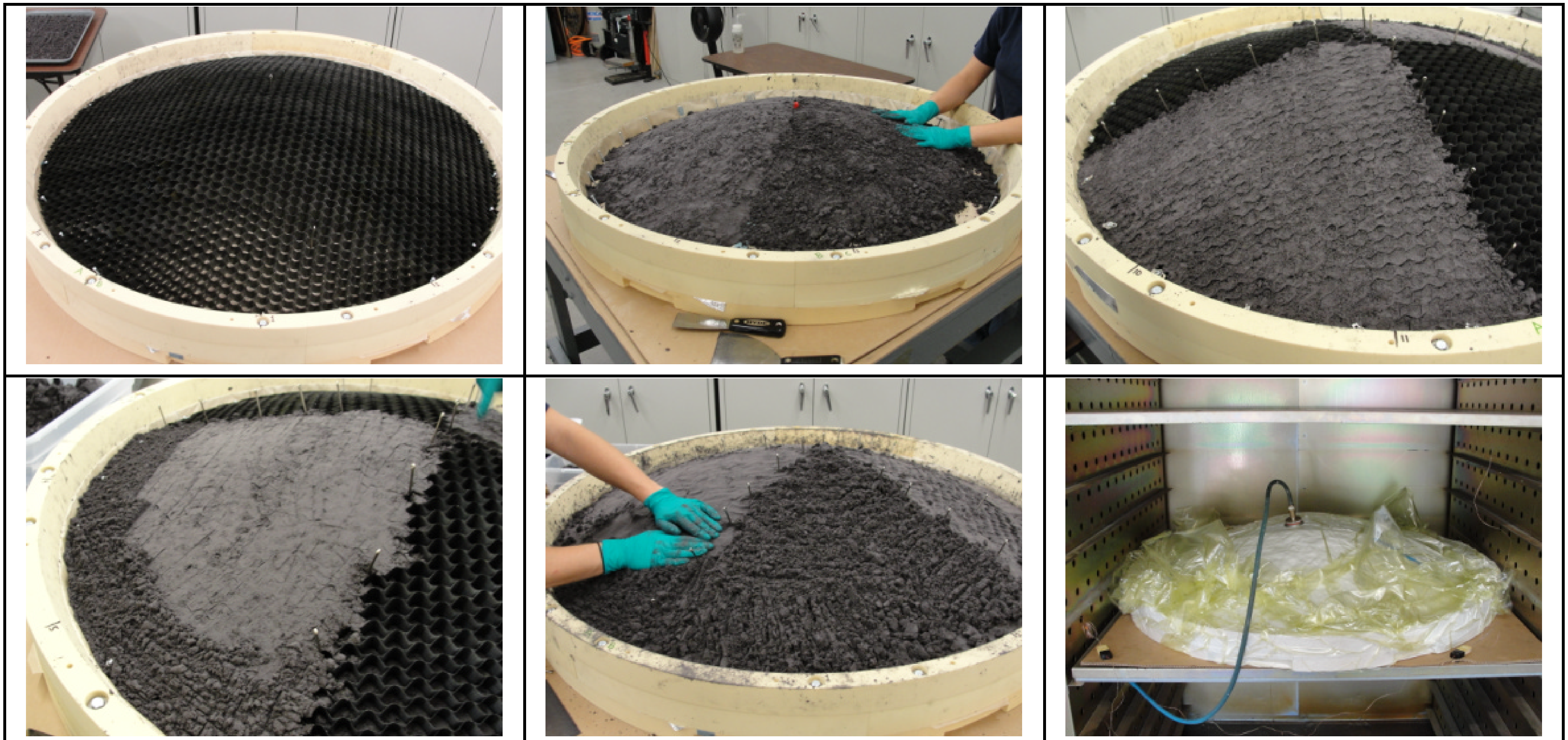


Oven Drying – Low Temperature

EXAMPLE MODULAR PACKING – 2.65-m AS SRAM-20 NOSE MODULE

From Start-to-Finish, Complete Packing Operation is a 7-hr Task for Two Packers Plus One Assistant

Ablator Compound is Mixed/Processed the Day Before and "Frozen" – Honeycomb Pre-Fitted to Mold



End of Packing – Mold in Oven Under Vacuum-Bag Pressure

2.65-m SRAM-20 MDU HEATSHIELD PRODUCED VIA NINE MODULES

Ablative Thicker, Denser, More Robust than Honeycomb-Packed Ablator of Other Mars Missions

Heatshield Final Thickness 1.25 in. – Produced to 1.40-in. Thickness with 0.25-in. Compound Overpack

18 Mix Batches Required for 2.65-m Heatshield

Module Type	Compound Mass	Mixed Bulk Volume	Mixed Bulk Volume	Drying Trays
Flank No.1	12,205 g	30 gal	4.01 ft^3	60
Flank No.2	12,205 g	30 gal	4.01 ft^3	60
Flank No.3	12,205 g	30 gal	4.01 ft^3	60
Flank No.4	12,205 g	30 gal	4.01 ft^3	60
Flank No.5	12,205 g	30 gal	4.01 ft^3	60
Flank No.6	12,205 g	30 gal	4.01 ft^3	60
Flank No.7	12,205 g	30 gal	4.01 ft^3	60
Flank No.8	12,205 g	30 gal	4.01 ft^3	60
Nose Part	12,502 g	31 gal	4.14 ft^3	62
Totals	**110.14 kg**	**271 gal**	**36.2 ft^3**	**542**

CONVENTIONAL PACKING NOT WORKABLE FOR LARGE HEATSHIELDS

Modular Ablator Manufacturing Enables Large Robust Heatshields (with Greater Quality)

Conventional Production – Difficulties for Large Heatshields

- Robust Heatshields Require Denser/Thicker Ablators
- Ablator Compounds Have Limited Working Life/Time
- Denser Ablators Require More Packing Effort/Time
- Thicker Ablators Require More Packing Effort/Time
- Too Many "Packers" Causes Process Interference
- Too Many Packers Needed to Meet Time Constraints

Modular Manufacturing – Advantages for Large Heatshields

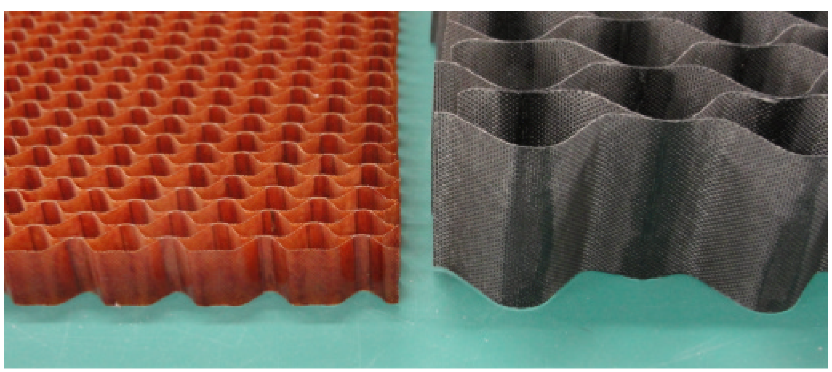
- Optimal Number of Packing Technicians with Better Access
- More Clock Time Available for High Quality Packing
- Provides for Two (Pre-Cure) Vacuum-Bagging Steps (for Low Spots)
- Allows Non-Destructive Inspection Before Bonding
- Enables High-Tech Implementation (e.g., Dual-Layer Systems)
- Eliminates Risk of Loosing Entire Heatshield (e.g., Working Life)
- Facilitates Concurrent Production of Structure and Heatshield

Packing Has Stringent Time Limitations

Commence Packing

Apply Vacuum Bag

MSL Backshell
0.50-in. Thick H/C
14.0 lb/ft^3 SLA Fill



2.65-m Aeroshell
1.40-in. Thick H/C
19.0 lb/ft^3 S-20 Fill

MSL BACKSHELL PACKED BUT 0.5 IN. THK WITH 14 LB/FT^3 COMPOUND

MSL Backshell Packing at LMA
SLA-561V Lightweight Ablator

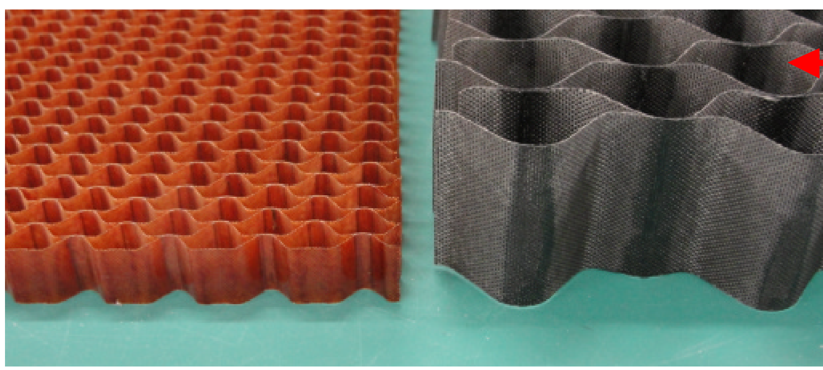
2.65-m Module Packing at ABL
SRAM-20 Midweight Ablator

"Phalanx" of Engineers/Technicians (16 in full photo)

Two Engineers/Technicians (optimal)

3.8 Times Mass Per Ft^2

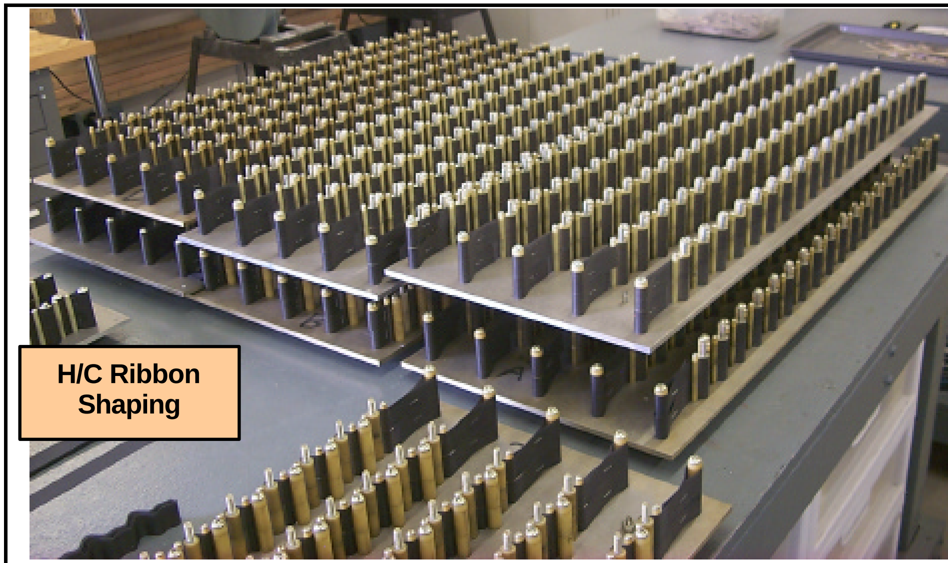
MSL Backshell
0.50-in. Thick H/C
14.0 lb/ft^3 SLA Fill

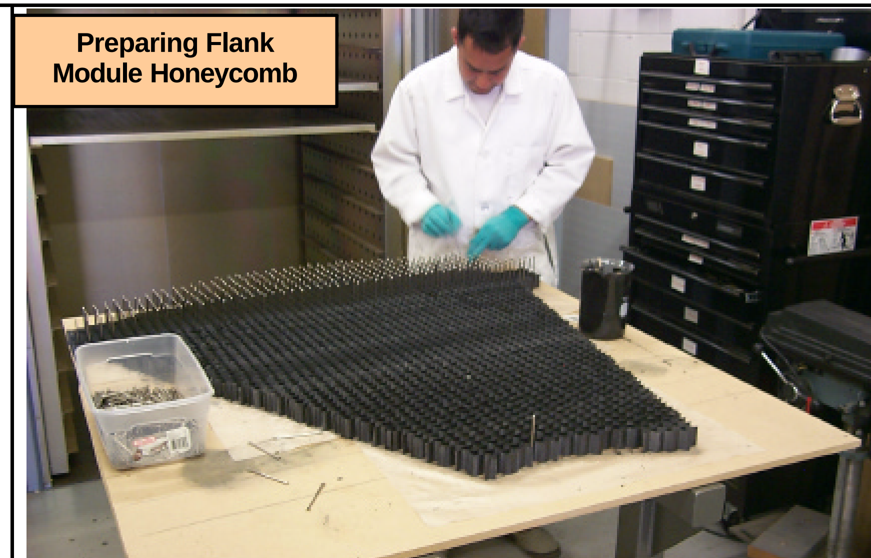


2.65-m Aeroshell
1.40-in. Thick H/C
19.0 lb/ft^3 S-20 Fill

ABL 1.0-IN. LARGE-CELL HONEYCOMB MADE IN HOUSE FOR 2.65-M A/S

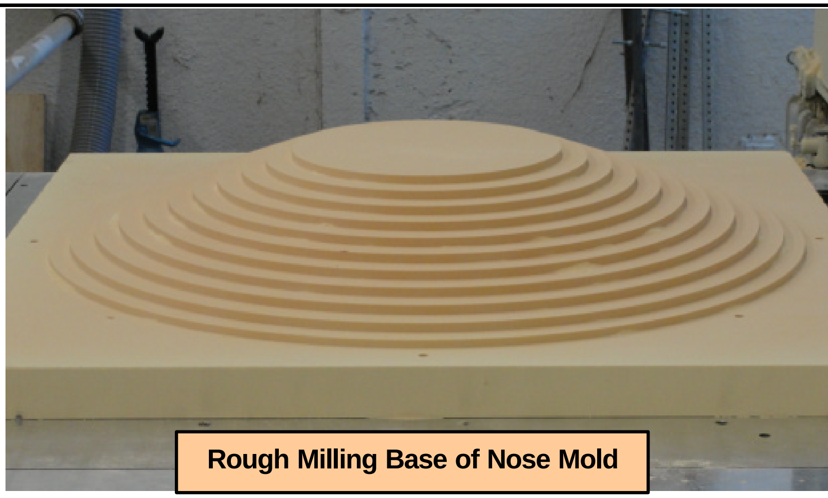
Process Includes Impregnating Fabric, Slitting into Ribbons, Shaping Ribbons, Assembly





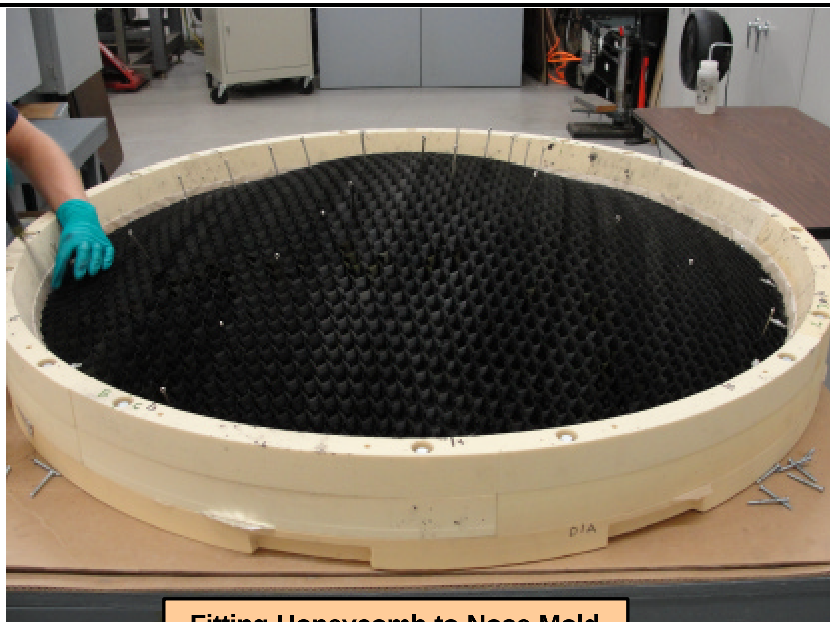
ABL PRODUCTION OF 2.65-M NOSE MOLD AND FITTING H/C PANEL

Mold for Nose Module Designed to Produce a Near-Net SRAM-20 Ablator Part

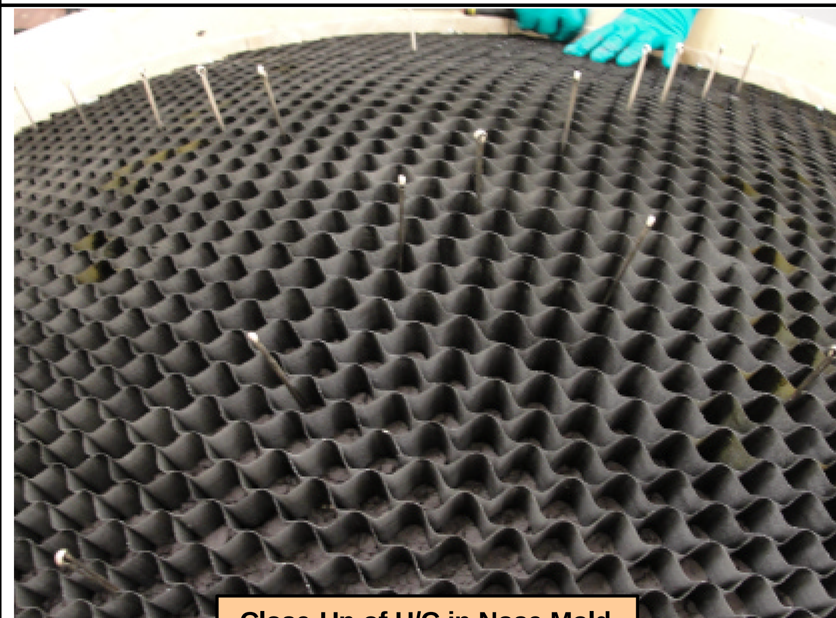


Rough Milling Base of Nose Mold

Thermally Stress Relieving Nose Mold Base



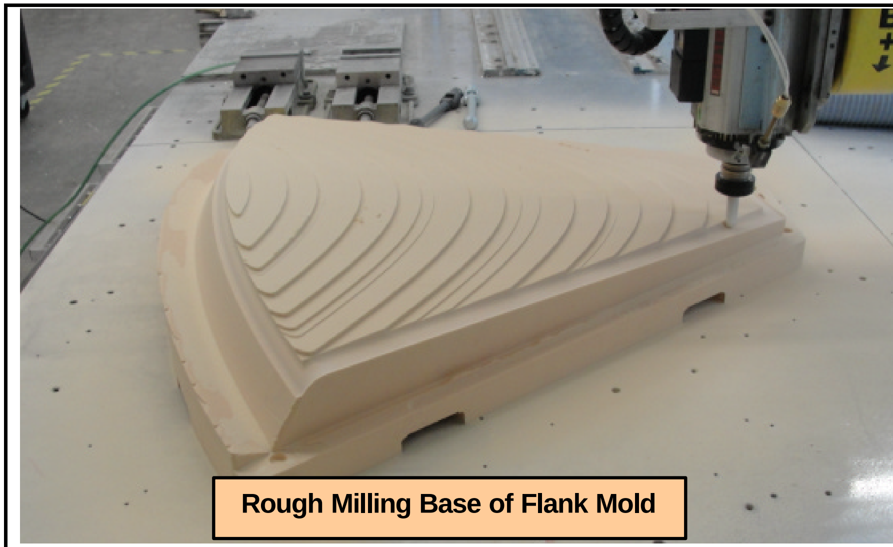
Fitting Honeycomb to Nose Mold



Close-Up of H/C in Nose Mold

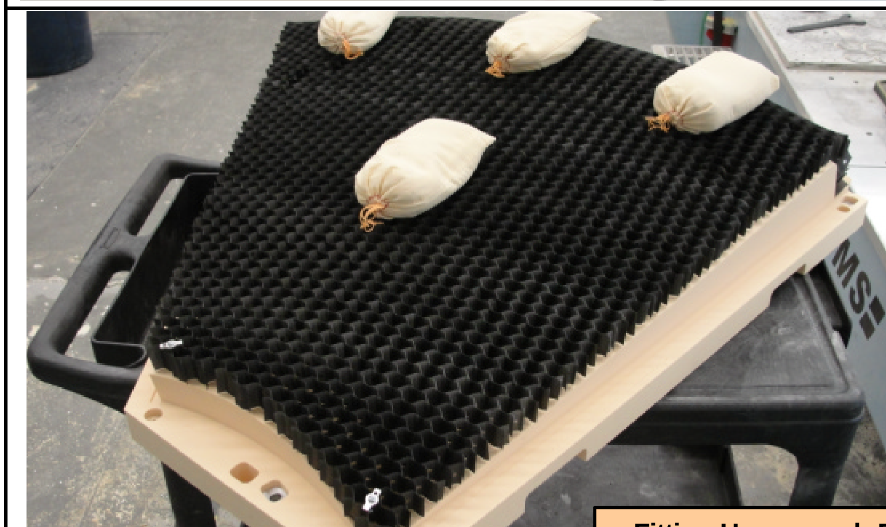
ABL PRODUCTION OF 2.65-M FLANK MOLD AND FITTING H/C PANELS

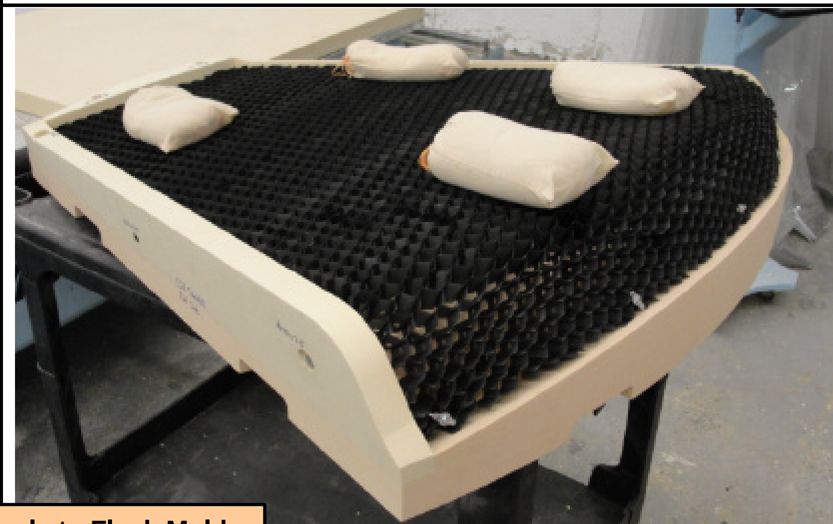
Mold for Flank Modules Designed to Produce a Near-Net SRAM-20 Ablator Part



Rough Milling Base of Flank Mold

Milled Base Portion of Flank Mold

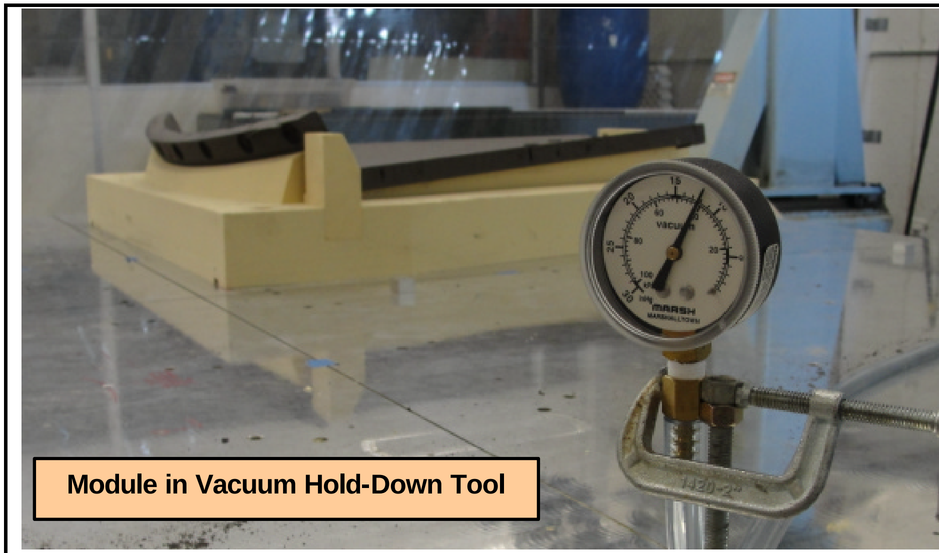




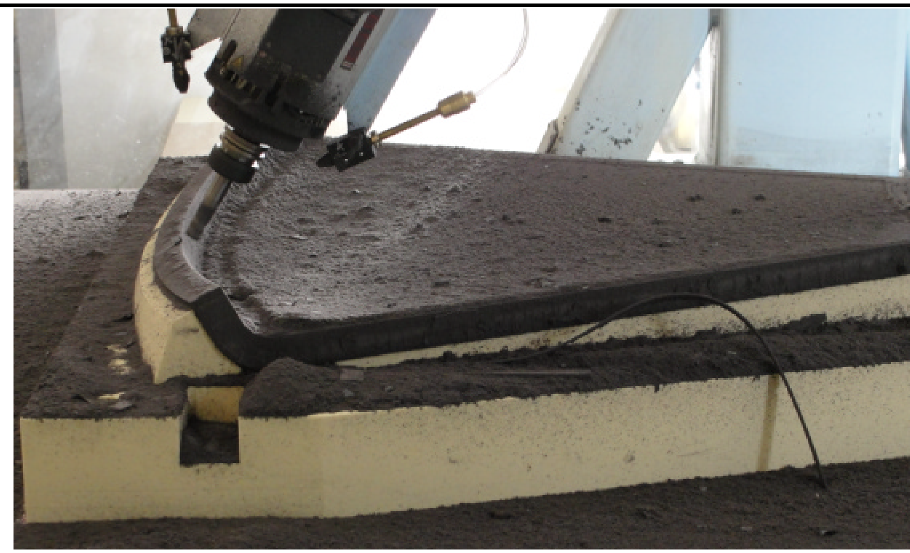
Fitting Honeycomb Panels to Flank Mold

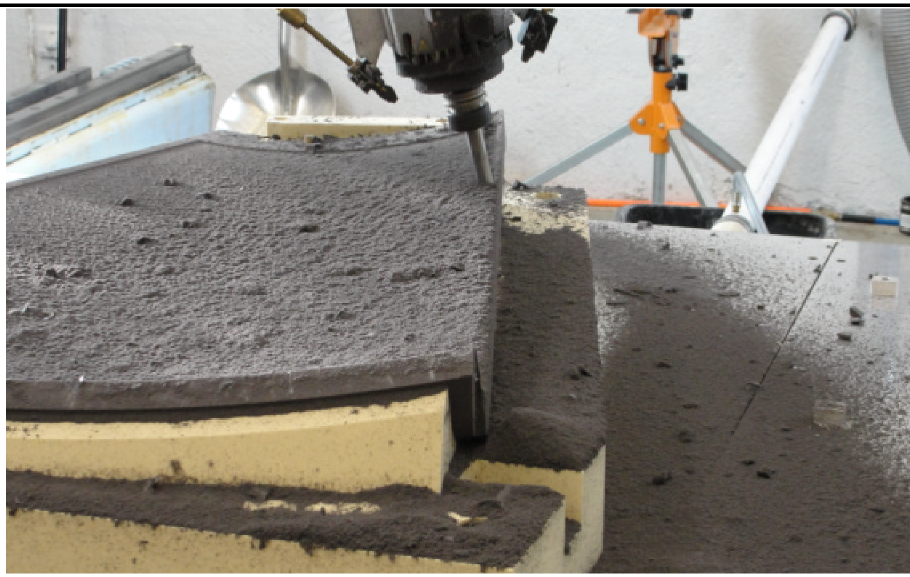
2ND MILLING DEFINES FLANK EDGES AND FINALIZES BOND SURFACE

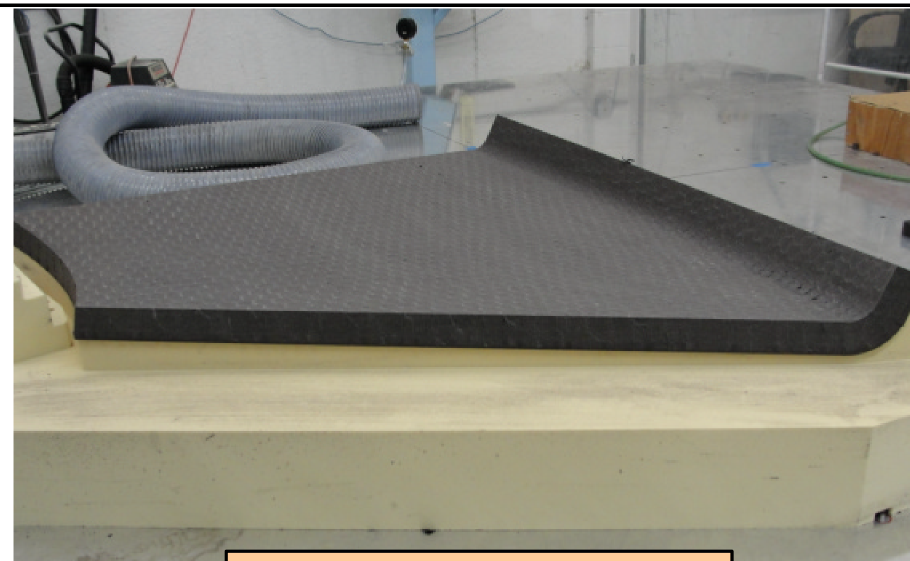
All Eight Large Flank Modules Receive 5-Axis Milling on Both External and Bond Surface



Module in Vacuum Hold-Down Tool



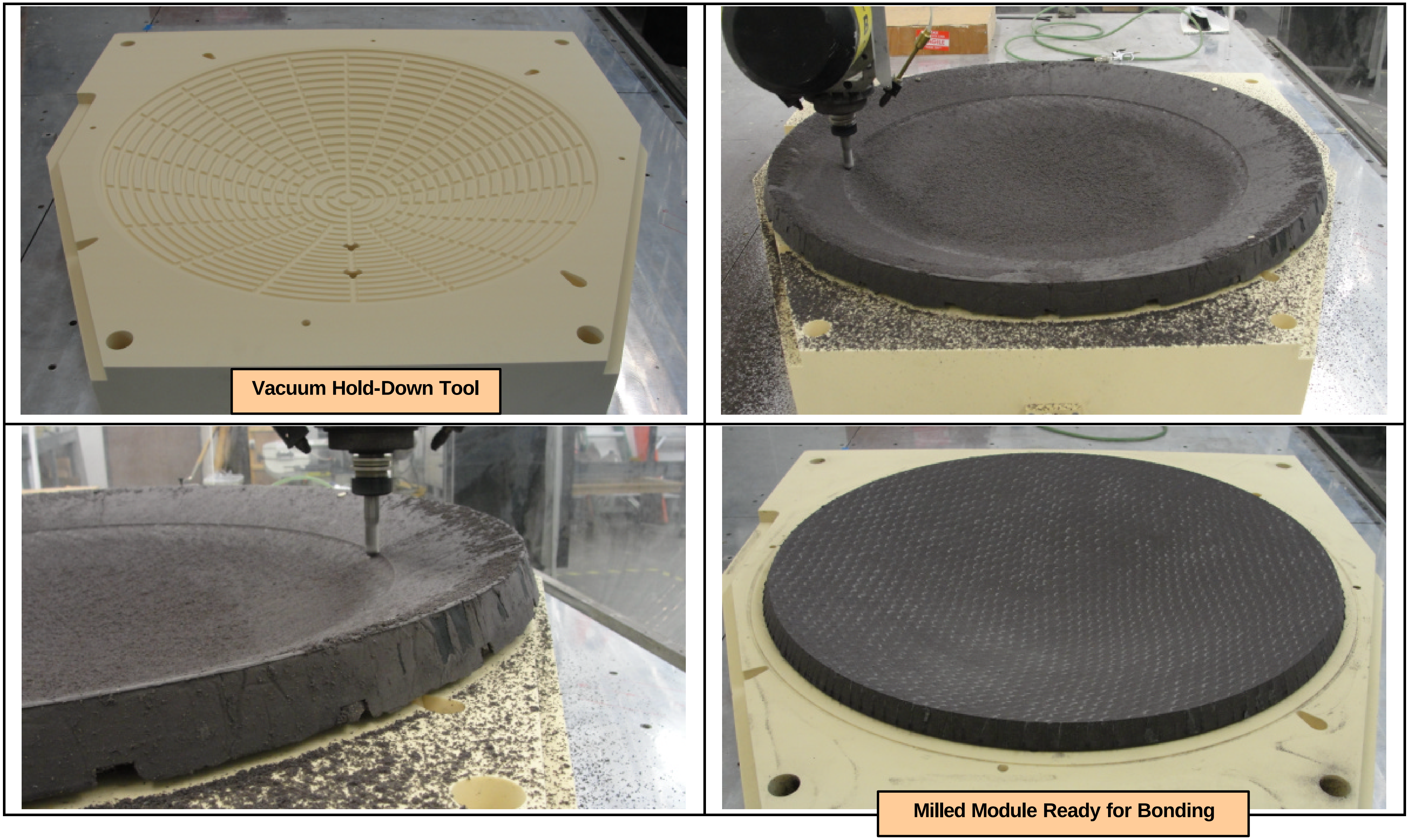




Milled Module Ready for Bonding

2ND MILLING DEFINES NOSE EDGE AND FINALIZES BOND SURFACE

Single Large Nose Module Receives 5-Axis Milling on Both External and Bond Surface



NINE SRAM-20 MODULES UNDERGOING FIT CHECKS BEFORE BONDING

Ablator Module Bonding Done with Epoxy-Phenolic Film Adhesive for 2.65-m Aeroshell

FINAL COMPLETE FIT-CHECK OF NINE MODULES WITH GAP SPACERS

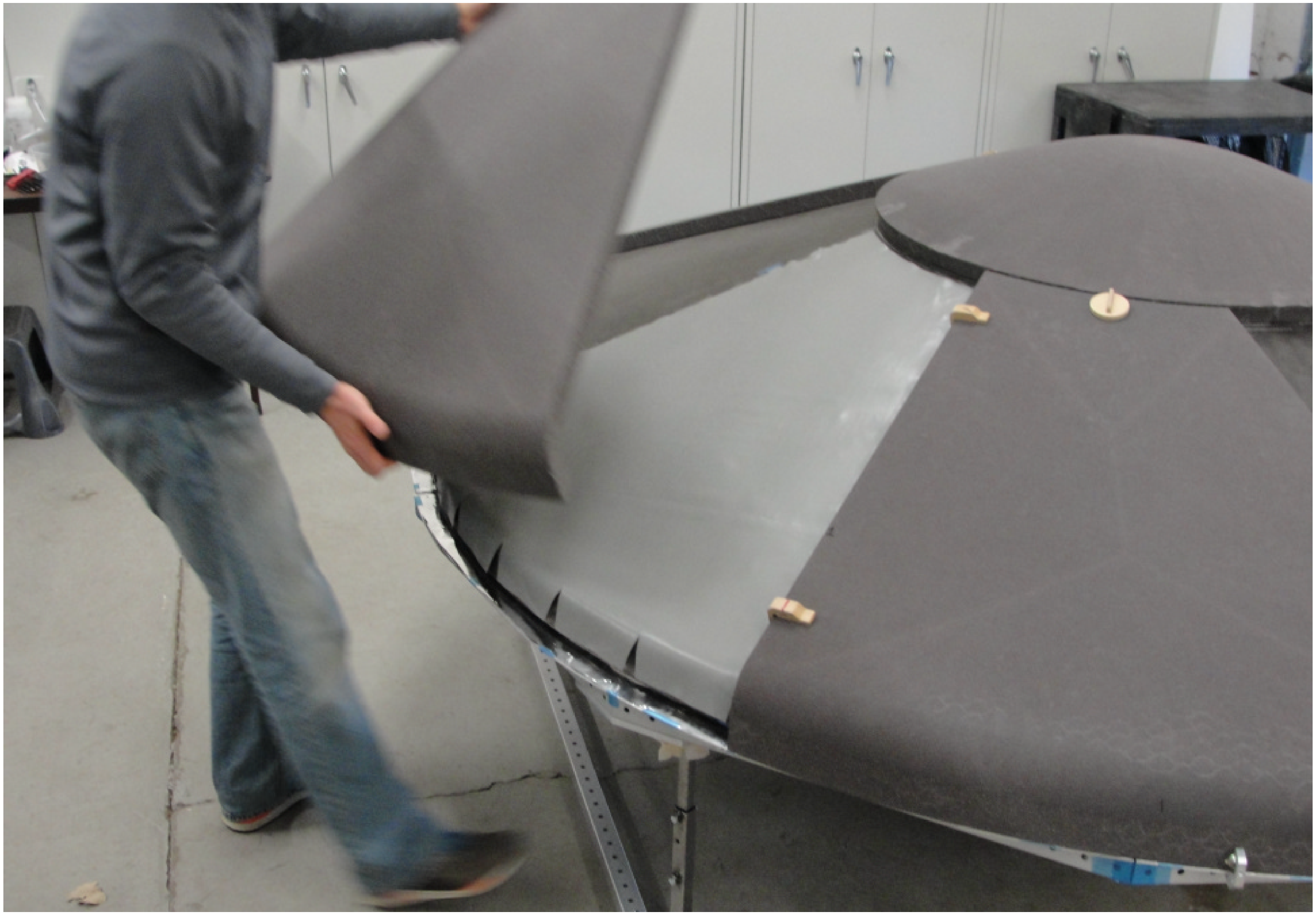
Engineered Gap Spacers Used to Maintain Precise Gap Widths for Subsequent Filling

SRAM-20 Ablator Used to Fill Gaps – Final Heatshield is 100% SRAM-20 !

BONDING NUMBER-2 SRAM-20 FLANK MODULE OF 2.65-M AEROSHELL

Bonding Operations are Facilitated by Cold Laboratory Temperatures

Inhibits/Maintains Tack of Film Adhesive to Workable Level



VACUUM-BAGGED AEROSHELL IN OVEN FOR CURING ABLATOR BOND

First Vac-Bag Oven Cycle is to Cure Film Adhesive that Bonds Modules to Structure

Second Oven Cycle is to Cure SRAM-20 Ablator Compound Packed into Intermodule Gaps

2.65-M SRAM-20 HEATSHILED READY FOR FINAL 5-AXIS CNC MILLING

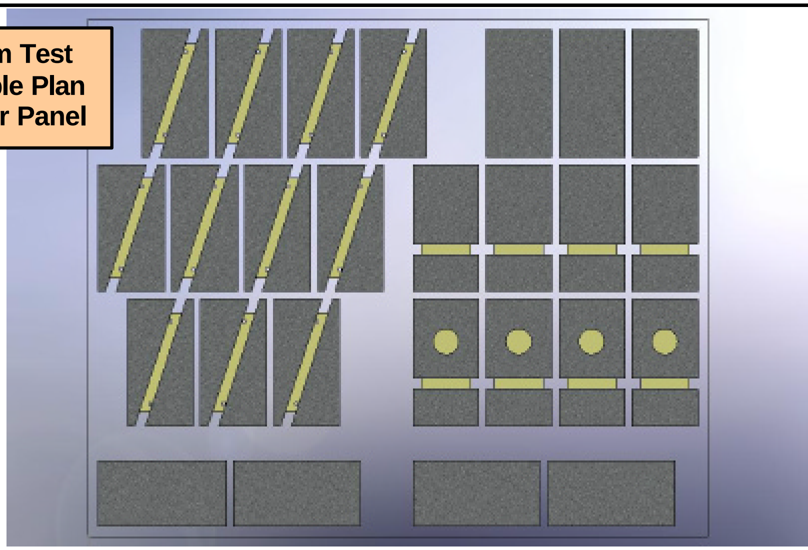
Intermodule Gaps Fully Packed and Cured Using SRAM-20 Ablator Compound

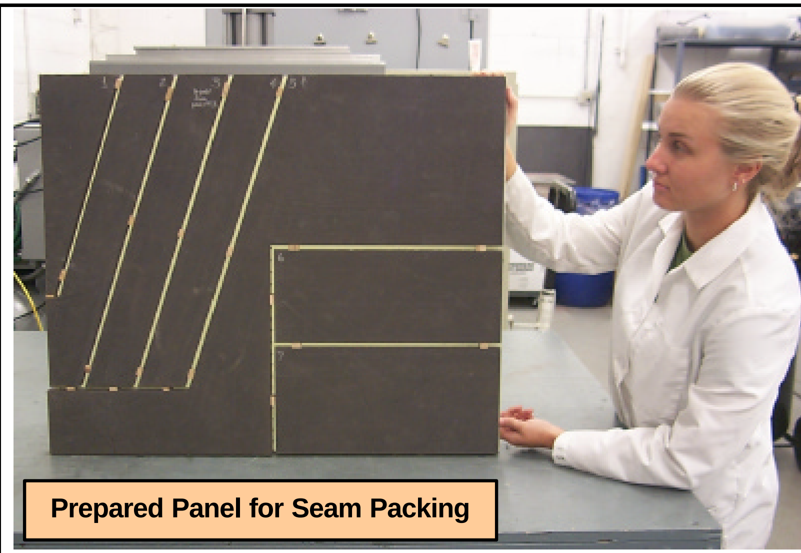
Final Milling Requires Large DMS 5-Axis Milling Machine with 10-ft Bed

DEVELOPING SEAM-PACKING PROCESS – PREPARING TEST SAMPLES

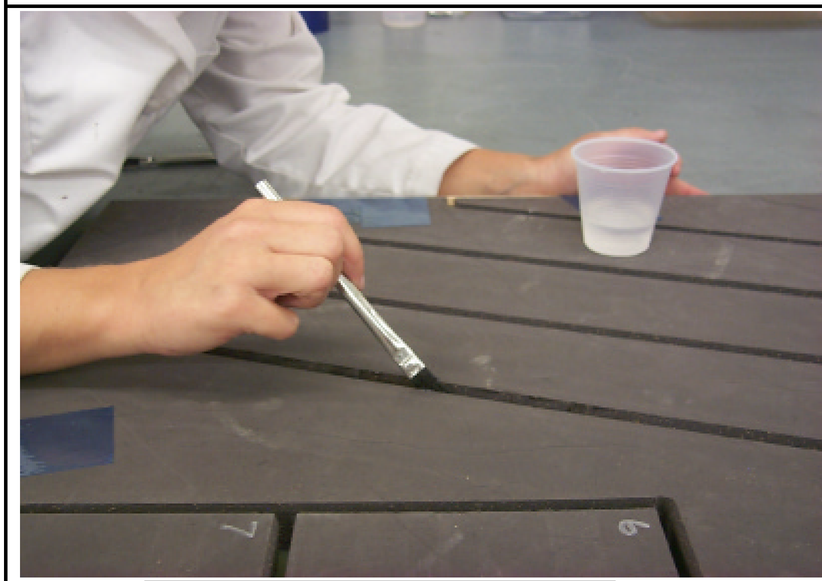
Packing Process for Intermodule Seams Validated by Arc-Jet Aeroshear Testing

Seam Test Sample Plan 26 Per Panel





Prepared Panel for Seam Packing

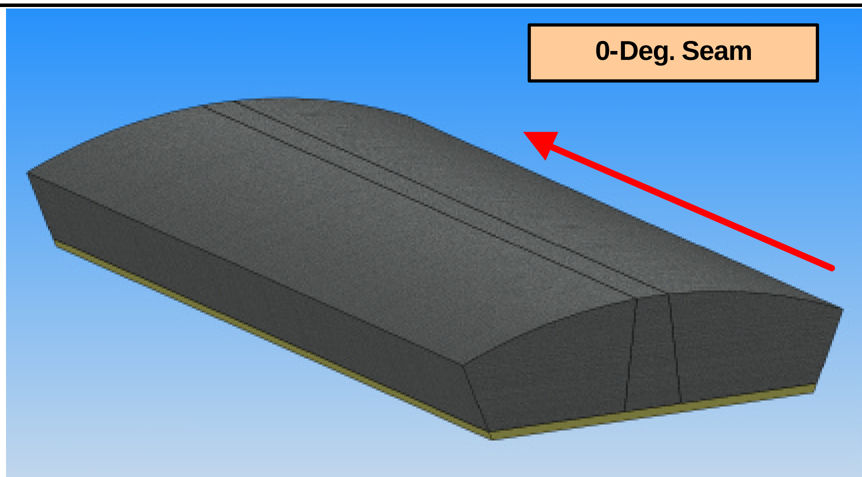


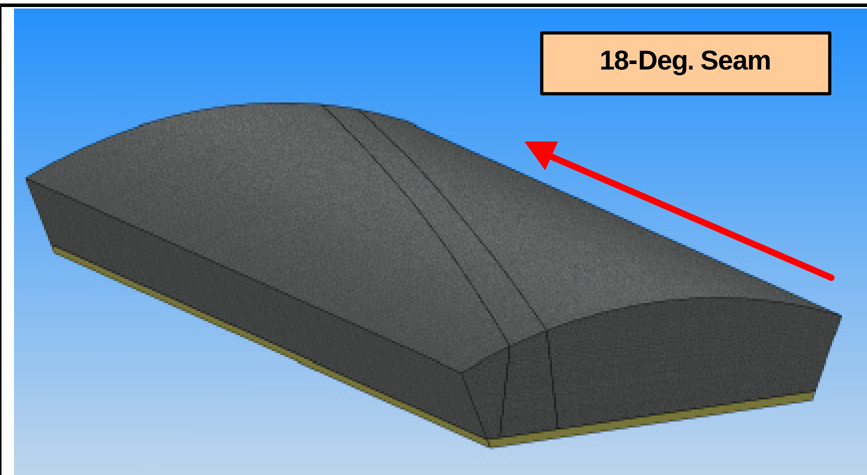
Appling Resin Wet Coat to Seams

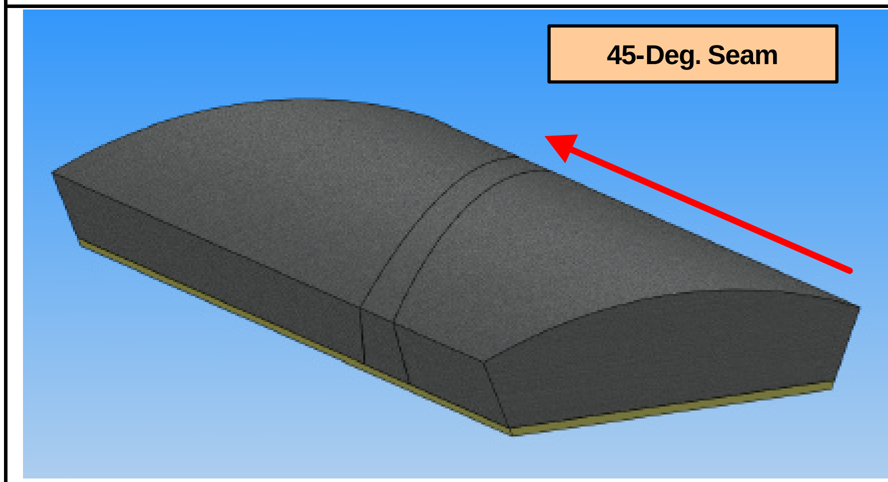
Packing with Ablator Compound

56 PACKED-SEAM AND CONTROL SAMPLES FOR ARC-JET TESTING

Aeroshear Samples are 6.0 x 3.0 x 0.8 In.- Tested to MSL-Developed Shear Environments



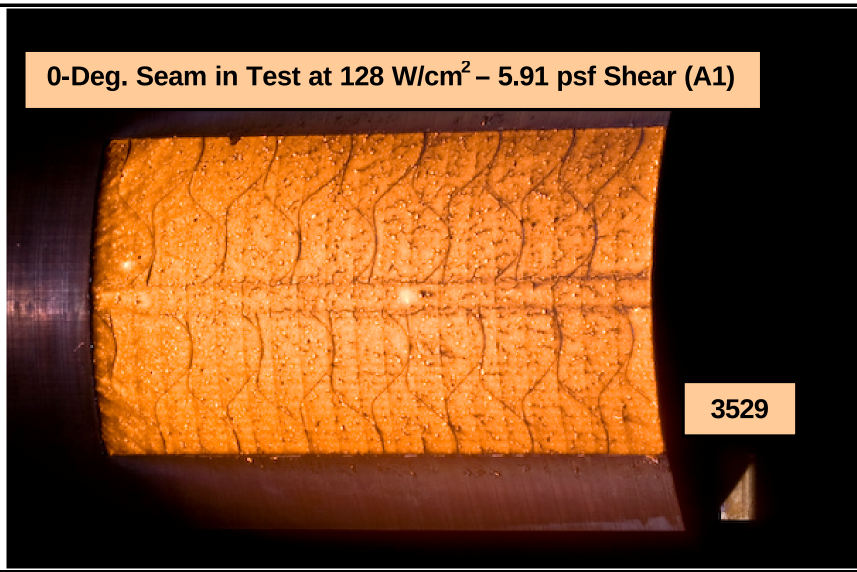


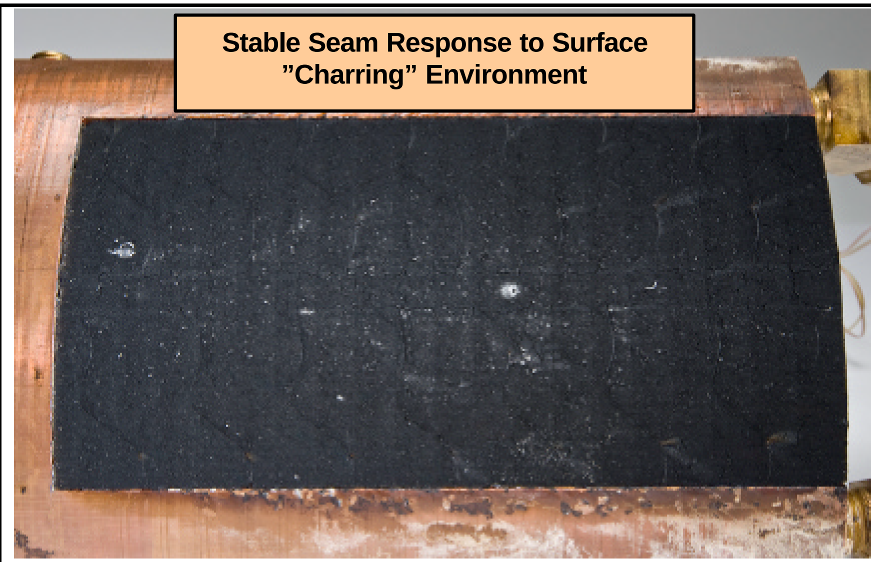


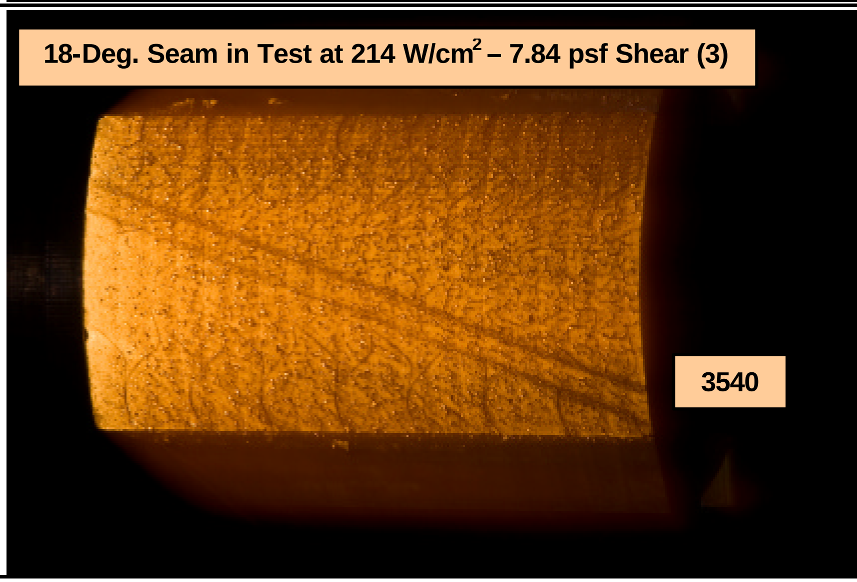
Aeroshear Samples Being Readied for Testing

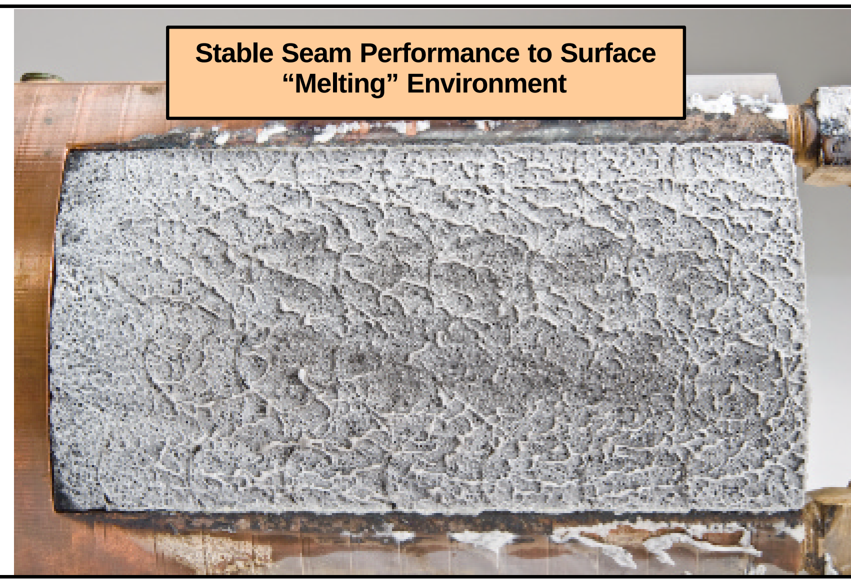
ALL SRAM-20 PACKED SEAMS SHOWED EXCELLENT PERFORMANCE

Seam Locations Showed Same Performance as Standard SRAM-20 in Honeycomb







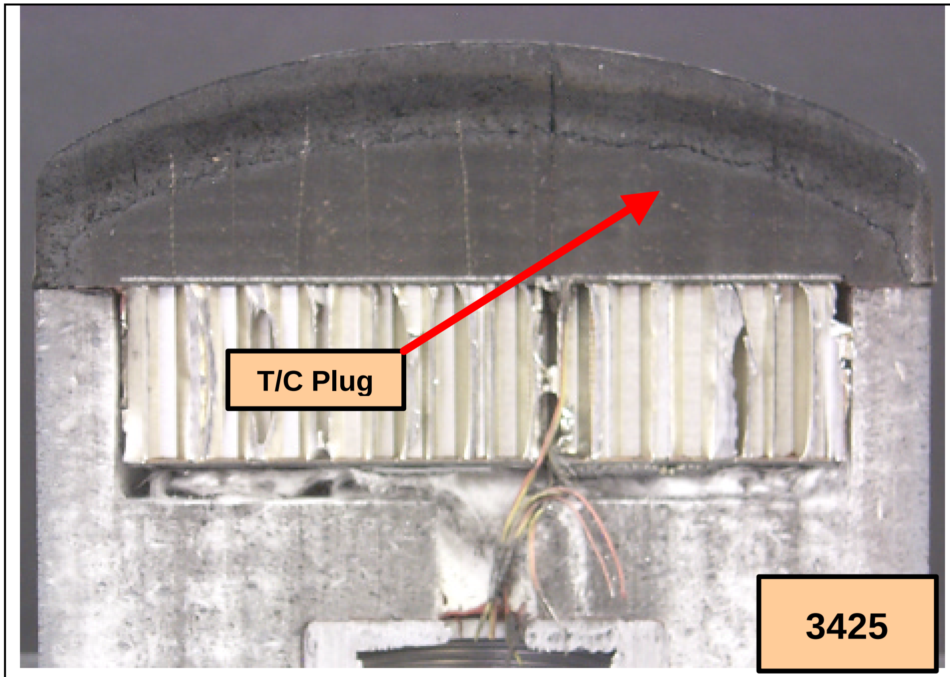


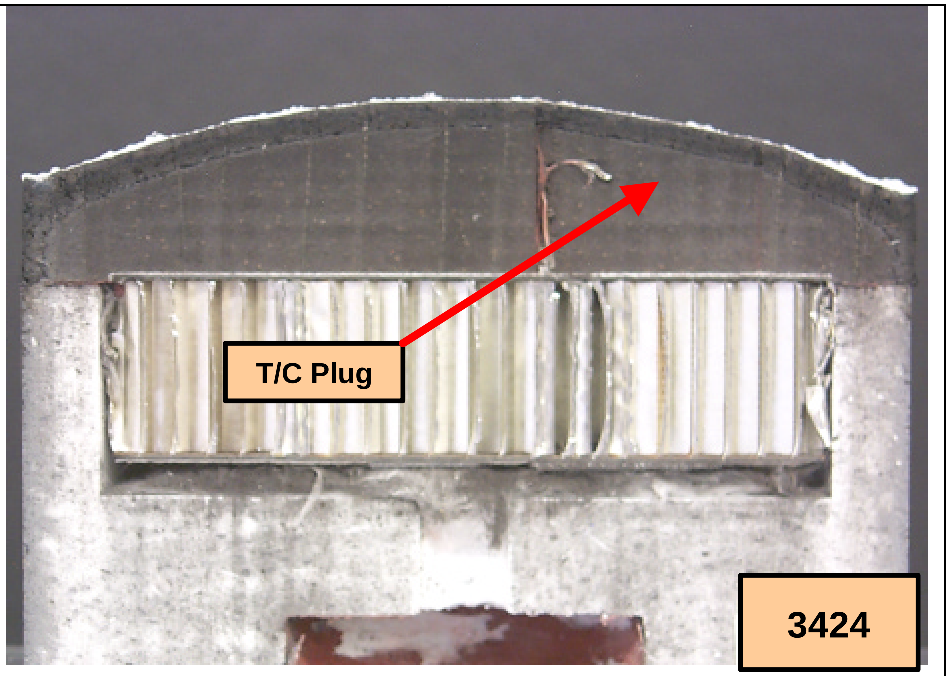
CHAR-LAYER GROWTH AND PERFORMANCE FOR CHARRING ABLATOR

Charring Ablator Develops Insulating Surface Char Layer During Ablation Process
SRAM-20 Silicone-Based Ablator has Optimal Performance to ~350 W/cm^2
Above 350 W/cm^2, Char Layer is Thin – Low-Density Phenolic Ablator Better
Arc-Jet Stagnation Test Series at NASA Ames Research Center

SRAM-20 Sample 3425 – 128 W/cm^2 for 160 sec
Surface Recession – 0.00 in.

SRAM-20 Sample 3424 – 254 W/cm^2 for 60 sec
Surface Recession – 0.33 in.

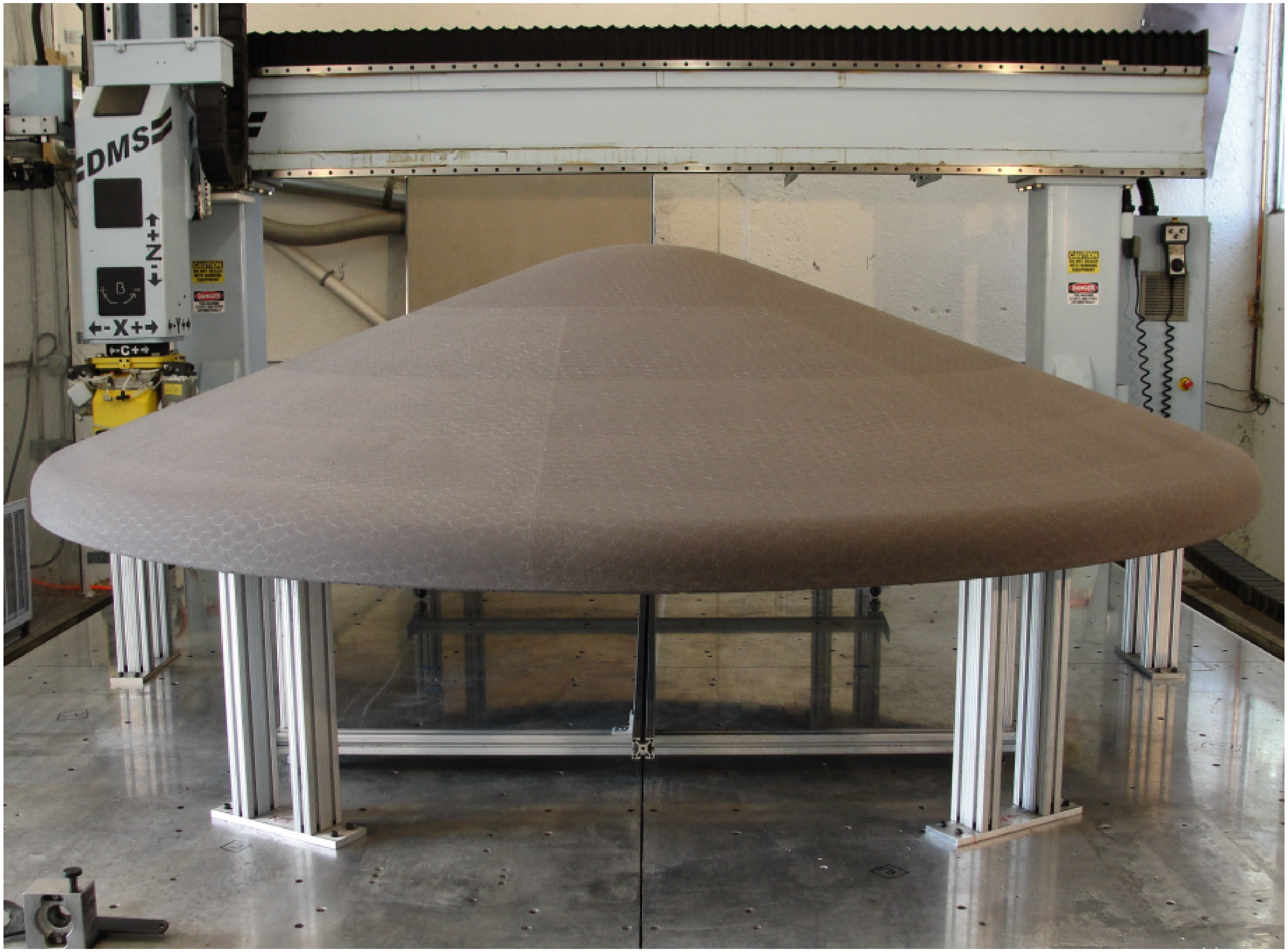




(New Millennium 5.0-In. Diameter Iso-Q Shaped Samples with Sandwich-Composite Substrates)

FULLY ASSEMBLED & MILLED 2.65-m MODULAR SRAM-20 AEROSHELL

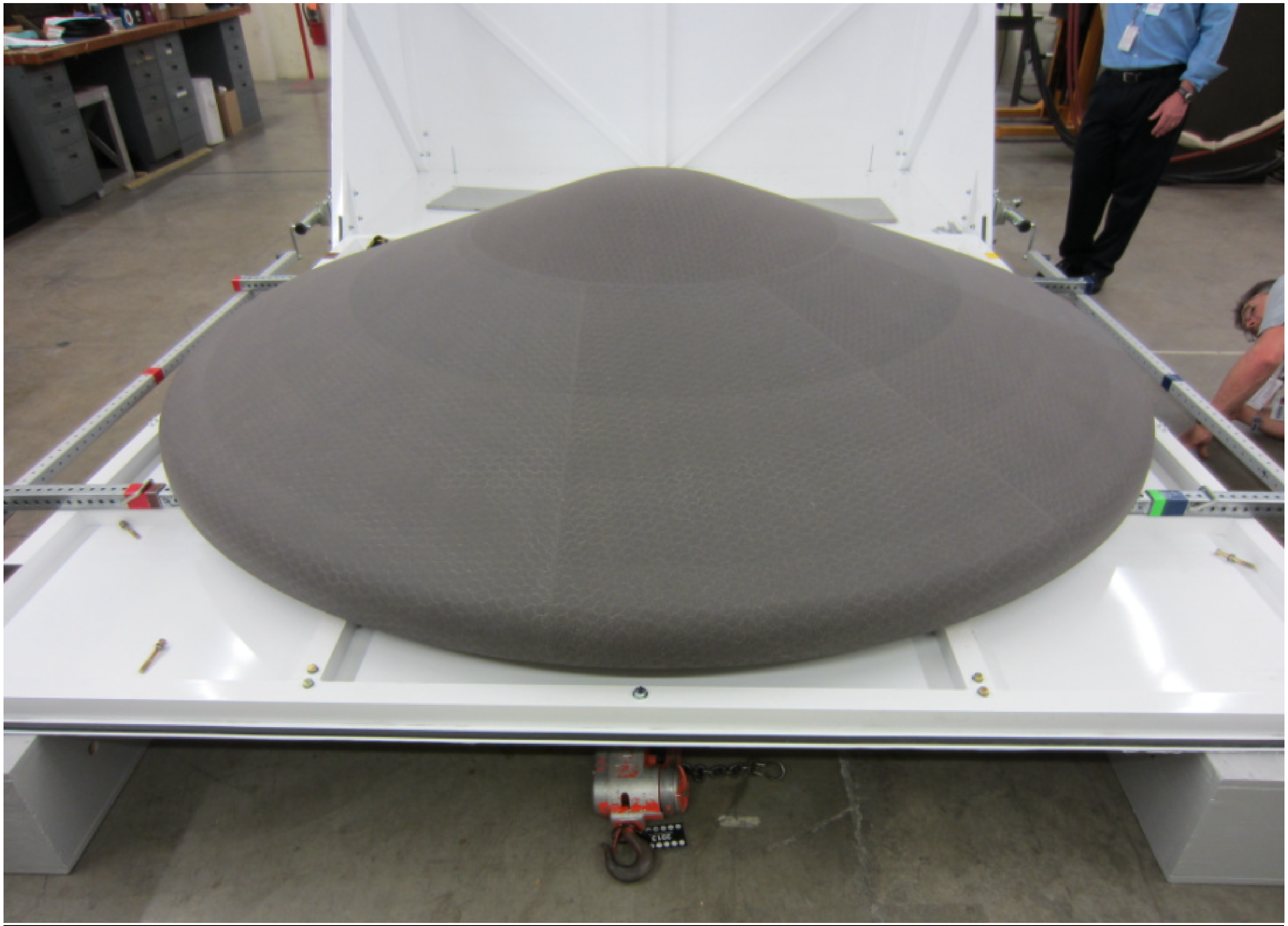
Eight SRAM-20 Flank Modules and One Nose Module with SRAM-20 Gap Filler Between Modules



Aeroshell Positioned on ABL's Large Five-Axis Milling Machine

DISPLAY PLAN FOR 2.65-m MODULAR SRAM-20 AEROSHELL AT IPPW-10

Photo Below Shows Aeroshell at Lawrence-Livermore Labs for Full-Up CT-Scan Testing



Aeroshell Mounted to Lid of Shipping Container